PATENT ABSTRACTS OF JAPAN

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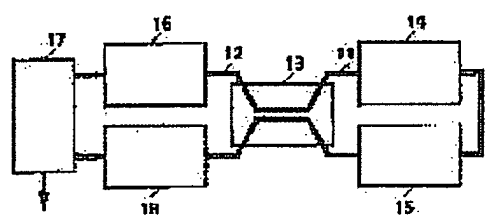
(54) PULSE LASER

(57)Abstract:
PURPOSE: To facilitate the stabilization of a pulse width against external disturbances such as a temperature and a vibration by a method wherein an optical modulator is provided in a resonator.
CONSTITUTION: First and second loops 11 and 12 which are composed of optical waveguides such as optical fibers are coupled with each other with a dB coupler 13 to constitute an 8-shaped laser resonator. An optical modulator 18 is provided in the resonator. The optical resonator 18 is driven with a mode locking frequency which is determined by the resonator length or with a frequency close to the harmonic of the mode locking frequency to realize a so-called hybrid mode locking oscillation in which passive mode locking and forced mode locking are simultaneously performed. With this constitution, a passive mode locking oscillation pulse can be forcibly synchronized by an electric signal controlling the optical modulator 18, so that a short wavelength light pulse oscillation which is stable against external disturbances such as a temperature and a vibration can be realized.



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CLAIMS

[Claim(s)]
[Claim 1] The pulse laser which is a pulse laser equipped with the nonlinear loop-formation mirror and the optical isolator into the optical resonator constituted by optical waveguide while using as the magnification medium optical waveguide which added rare earth ion, and is characterized by providing a light modulation element in the above-mentioned resonator.

DETAILED DESCRIPTION

[Detailed Description of the Invention]
[0001]
[Industrial Application] This invention relates to the pulse laser in which actuation stable at high power and a high repeat with high utility value is possible in the field of ultra high-speed optical communication, optical information processing, and optical sensing.
[0002]
[Description of the Prior Art] 1.55-micrometer band passivity mode locking optical fiber laser using the nonlinear optics property of an optical fiber is developed using the optical fiber which added Er ion as a magnification medium, and various application as the ultrashort pulse light source is expected. Moreover, semiconductor laser excitation is possible for this pulse laser, and it has high practicality from the ability to miniaturize.
[0003] The basic configuration of an example of this kind of pulse laser is shown in drawing 5 . As shown in this drawing, the laser cavity of the shape of a character of 8 is constituted by connecting the 1st loop formation 1 and 2nd loop formation 2 through 3dB coupler 3. The optical fiber 5 as the polarization compensator 4 and a nonlinear optics medium, the coupler 6 for excitation optical multiplexing, and the erbium (Er) ion addition fiber 7 are infixed in the 1st loop formation 1, the optical isolator 8 and the coupler 9 for outgoing radiation light ejection are infixed in the 2nd loop formation 2, respectively, and the 1st loop formation 1 functions as a nonlinear loop-formation mirror.
[0004] In this pulse laser, by introducing the pump light from semiconductor laser etc. from the coupler 6 for excitation optical multiplexing, and exciting the absorption band of Er ion of Er ion optical fiber 7, switching of a nonlinear loop-formation mirror takes place, and optical fiber laser carries out a passive mode locking oscillation. Here, it circulates through light as follows in the character-like resonator of 8. The light pulse which passed along the optical isolator 8 circulates through the 1st loop formation 1 which is the nonlinear loop-formation mirror which consists of 3dB coupler 3, the polarization compensator 4, an optical fiber 5, a coupler 6 for excitation optical multiplexing, and an Er ion addition optical fiber 7 right-handed rotation and in the counterclockwise direction, and returns to the 2nd loop formation 2 which it was again multiplexed with 3dB coupler 3, and the optical isolator 8 entered. Then, only the pulse spread to an one direction will carry out incidence to a nonlinear loop-formation mirror again with an optical isolator 8, and the pulse spread to an opposite direction is prevented. When optical

reinforcement is small, the phase contrast of the light which circulates through the inside of a nonlinear loop-formation mirror is zero, and a pulse is prevented from the property of a nonlinear loop-formation mirror by the incidence port with the return optical isolator 8. If optical reinforcement becomes high, while spreading the inside of an optical fiber, phase contrast arises between the propagation directions of a pulse by self-phase modulation, and light switches to an outgoing radiation port other than an incidence port. In case the pulse which grew from spontaneous emmision luminous-intensity fluctuation spreads the inside of a resonator in the above-mentioned path, light modulation is received with the period which was in agreement with the pulse circumference time amount of a resonator with switching of a nonlinear loop-formation mirror, and a passive mode locking oscillation is caused. The self-phase modulation in an optical fiber is very high-speed, and a very short high power mode locking pulse train is acquired as a result of high-speed switching of a nonlinear loop-formation mirror, and the soliton effectiveness. [0005] In addition, it is reported that Richardson and others realized the period of 10GHz, and passive mode locking actuation beyond presumed peak intensity 50W repeatedly by pulse width 320fs by the system shown in drawing 5 (D. J.Richardson et al;"320fs SOLITON GENERATION WITH PASSIVELY MODE-LOCKED ERBIUM FIBER LASER.";ELectron Lett.1991.27.p.730-732). [0006]
[Problem(s) to be Solved by the Invention] However, passive mode-locking actuation of said pulse laser is very sensitive to fluctuation of the plane of polarization by few change and impacts of optical-resonator length in which induction is carried out by the temperature change, for example, the temperature-change width of face which stabilizes and operates is 1 or less time, and operates to stability only less than 1 minute, but the trouble about the stability of actuation -- two or more pulses occur or fluctuation of pulse separation becomes large -- which should be solved practically is in the mode-locking primitive period which becomes settled in cavity length. [0007] This invention aims at being high power and offering the pulse laser in which stable actuation is possible by the high repeat in view of such a situation.
[0008]
[Means for Solving the Problem] The pulse laser concerning this invention which attains said purpose is a pulse laser equipped with the nonlinear loop-formation mirror and the optical isolator into the optical resonator constituted by optical waveguide, and is characterized by providing a light modulation element in the above-mentioned resonator while it uses as a magnification medium optical waveguide which added rare earth ion.
[0009]
[Function] The so-called hybrid mode locking oscillation which performs both passive mode locking and compulsive mode locking to coincidence is realized by arranging an optical modulator in a resonator and driving an optical modulator on the frequency near the mode locking frequency which becomes settled by cavity length, or its harmonic frequency. Since a passive mode locking oscillation pulse can be compulsorily synchronized with the electrical signal which controls an optical modulator by this, a very stable short light pulse oscillation is attained to disturbance, such as temperature and vibration. Moreover, since this pulse laser generates a light pulse on the frequency which was completely in agreement with the electrical signal which drives an optical modulator, between the light source and a detection system, it can synchronize electrically and various application of it is attained in optical information processing or optical sensing.
[0010]
[Example] Hereafter, this invention is explained based on an example.

[0011] The basic configuration of the pulse laser of this invention is shown in drawing 1 . As shown in this drawing, by connecting the 1st loop formation 11 and 2nd loop formation 12 which consist of optical waveguides, such as an optical fiber and flat-surface optical waveguide, through 3dB coupler 13, the laser cavity of the shape of a character of 8 is constituted, and the optical amplification medium 14 and the nonlinear optics medium 15 are arranged at the 1st loop formation 11. It is arranged in the 1st loop formation 11 at the location where the optical amplification medium 14 and the nonlinear optics medium 15 are unsymmetrical, and the 1st loop formation 11 functions as a nonlinear optics loop-formation mirror. Moreover, the optical isolator 16, the optical coupler 17 for output light ejection, and optical modulator 18 for 1.5-micrometer bands are arranged at the 2nd loop formation 12. Here, an optical isolator 16, the optical coupler 17 for output light ejection, and an optical modulator 18 can be mutually arranged in the 2nd loop formation 12 in the location of arbitration. In addition, in the 2nd loop formation 12, the necessary polarization compensator which does not carry out location illustration can be arranged if needed.
[0012] As an optical amplification medium 14, the optical fiber and flat-surface optical waveguide which added rare earth ion, such as Er ion, are used. Since gain required of short waveguide length can be acquired in this by using the flat-surface optical waveguide which can be added by high concentration for rare earth ion, it becomes possible to raise the repeat frequency of a mode locked laser. In addition, as rare earth ion, others and neodium (Nd) ion, PURASEOJIUMU (Pr) ion, etc. can be mentioned. [ion / Er]
[0013] As a nonlinear optics medium 15, a silica glass fiber and flat-surface optical waveguide are usable. A very short pulse can be generated using the optical soliton effectiveness by using the optical fiber and flat-surface optical waveguide which adjusted distribution to the negative value with 1.5-micrometer band especially. Moreover, the waveguide which can spread light, with plane of polarization maintained, such as flat-surface optical waveguide and polarization maintaining optical fiber, is useful, when there is no problem of fluctuation of the plane of polarization by disturbance and mode locking actuation is carried out at stability.
[0014] As for 3dB coupler 13 or the optical turnip 17 for output light ejection, the directional coupler of an optical fiber mold with the high controllability of a branching ratio with small optical loss or a flat-surface waveguide mold is used. Since cavity length can be shortened like the case of an optical amplification medium by using a flat-surface optical waveguide type directional coupler, it is advantageous to high repeat actuation of a mode locked laser.
[0015] As an optical isolator 16 for 1.5-micrometer bands, an optical isolator with the optical fiber for I/O and the integrated thing with flat-surface optical waveguide can be used. It has the high polarization dependency which the flat-surface waveguide integration mold optical isolator suitable for the high repeat of a light pulse has the structure which put the YIG magneto optics crystal permuted with Bi ion with the minute polarizer which consists of mutual multilayers of a dielectric and a metal, and could make it 200 micrometers or less in thickness, and a thin shape, and was suitable for single polarization actuation. Therefore, high isolation can be obtained according to the magneto-optical effect by impressing a magnetic field in parallel with the propagation direction of light. In order to integrate this optical isolator with flat-surface optical waveguide, a slot is formed by etching or machining so that the optical waveguide used as an optical path may be crossed, it arranges so that it may become the suitable polarization direction about a thin optical isolator in this slot, and it embeds with the optical adhesives which optical waveguide and a refractive index adjusted, and the magnet for magnetic field impression is arranged on this after immobilization. In order to attain low loss-ization at this time, while

becoming thin about the thickness of an optical isolator, the diameter of the mode field of the part which inserts an optical isolator is enlarged, and it is still more nearly required to double the refractive index of optical adhesives with an optical isolator etc. By making full use of such a low loss-ized technique, 1dB or less of insertion losses and the high quality integration optical isolator beyond isolation 20dB are realizable.

[0016] The various optical modulators using the electro-optical effect and an acousto optic effect as an optical modulator 18 are used. Both intensity modulation and the phase modulation of a modulation technique are usable. The electrooptical modulator suitable for a high repeat has the type in which the electrode was formed on the optical waveguide which used and formed the ion diffusion method in the lithium-niobate crystal front face.

[0017] In order to operate the pulse laser of this this invention, an optical modulator 18 is driven with the mode locking repeat frequency decided from cavity length, or its harmonic frequency. The so-called thing [carrying out hybrid mode locking actuation] which perform both passive mode locking and compulsive mode locking to coincidence by this is possible. If a difference with the drive signal frequency of an optical modulator 18, a mode locking frequency, or its harmonic frequency is less than several Hz, a hybrid mode locking condition is maintainable. For this reason, it is the frequency which was not based on minute change of the cavity length by the temperature change, but was completely in agreement with optical modulator drive signal frequency, and a driving signal and the pulse corresponding to 1 to 1 can be generated. By driving an optical modulator 18 by the higher harmonic of a mode locking frequency, it becomes possible to raise pulse repetition frequency to the frequency which was in agreement with drive signal frequency.

[0018] Moreover, in the pulse laser of this invention, by constituting all or some of resonators using polarization maintaining optical fiber with polarization holdout, or flat-surface optical waveguide, fluctuation of the plane of polarization which a mechanical shock etc. produces owing to can be inhibited or controlled, and stabilization of a mode locking pulse is possible.

[0019] The configuration of the pulse laser concerning the 1st example is shown in drawing 2 . The laser cavity of the shape of a character of 8 is constituted by connecting the 1st loop formation 21 and 2nd loop formation 22 through the optical fiber coupler 23 with the branching ratio of 3dB with 1.55-micrometer band, as shown in this drawing. Er ion addition optical fiber which is the optical fiber 25, the 0.98 / 1.55WDM coupler 26 for an excitation light input, and magnification medium of 1.55-micrometer negative distribution which are the polarization compensator 24 and a nonlinear medium at the 1st loop formation 21 (Er concentration of 500 ppm) The optical isolator 28 and the optical coupler 29 for outgoing radiation light ejection are arranged for 27 die length of 15m at the 2nd loop formation 22, respectively. Moreover, the acoustooptics component 30 as an optical modulator is arranged at the 2nd loop formation 22, and the driver 31 for acoustooptics components is connected to the acoustooptics component 30. Furthermore, DC power supply 32 and an oscillator 33 are connected to the acoustooptics component driver 31. The perimeter of the character type ring resonator of 8 of this pulse laser is 50m, and a mode locking frequency is 4MHz. In addition, as the excitation light source for introducing PORUPU light (excitation light) through the WDM coupler 26, strained layer superlattice semiconductor laser (oscillation wavelength of 0.98 micrometers, 100mW of optical outputs) was used.

[0020] In the pulse laser of this example, through the WDM coupler 26, incidence of the excitation light is carried out to Er ion addition optical fiber 27, it carried out passive mode locking actuation, and the oscillation condition that two or more pulses existed in the pulse

repetition period which adjusts excitation light power and the polarization compensator 24, and is determined by cavity length was acquired. When the acoustooptics component 30 was driven on the frequency near pulse repeat fundamental frequency by this condition at 10dB of extinction ratios, the process which shifts to the hybrid mode locking condition that the oscillation period of an outgoing radiation light pulse is completely in agreement with the period of a sound component driving signal, and only one pulse exists in a drive signal cycle was observed with the photodetector and the oscilloscope. The improvement of the property of continuing generating the short pulse of high power, without this hybrid mode locking operating state having stable pulse separation compared with passive mode locking operating state, and being maintained for a long time for 10 minutes or more being observed, and a frequency changing at all to change of the outside air temperature of abundance was found. Moreover, the acoustooptics component drive frequency band which can obtain a hybrid mode locking oscillation was 4Hz. A pulse tip output is 1W and the full width at half maximum of the pulse evaluated with the autocorrelation plan became clear [that it is 800 femtoseconds]. Furthermore, when the drive frequency of the acoustooptics component 30 was driven according to the 2nd harmonic frequency of a mode locking frequency, it became clear that a hybrid mode locking oscillation is realizable on the repeat frequency of 8MHz which is in agreement with the modulation frequency of the acoustooptics component 30.

[0021] By arranging an acoustooptic modulator by this example at the character type fiber laser resonator of 8, stabilization of pulse separation is possible and it is clear for a high repeat pulse oscillation to be attained by the higher-harmonic drive of an acoustooptic modulator.

[0022] The configuration of the pulse laser concerning the 2nd example is shown in drawing 3 . Since this example is the same as that of the 1st example except using an electro-optics component instead of an acoustooptics component as a light modulation element, the explanation which gives the same sign to the member which shows the same operation, and overlaps is omitted. Moreover, cavity length and a mode locking frequency are the same as the 1st example. The light modulation element of this example is the lithium-niobate optical waveguide type electro-optics modulator 34 on the strength which diffused and produced titanium ion, and the oscillator 35 is connected to the electro-optics modulator 34 on the strength.

[0023] In the pulse laser of this example, incidence of the excitation light from strained layer superlattice semiconductor laser was carried out to Er ion addition optical fiber 27 through the WDM coupler 26 like the 1st example, and the Er ion addition optical fiber 27 concerned was excited, excitation light power and the polarization compensator 23 were adjusted, and it changed into the passive mode locking oscillation condition. And when the electro-optics component 34 was made to drive by 10dB of extinction ratios near the mode locking fundamental frequency, the process which shifts to the hybrid mode locking condition that the oscillation period of an outgoing radiation light pulse is completely in agreement with the period of an electro-optics component driving signal, and only one pulse exists in a drive signal cycle was observed with the photodetector and the oscilloscope. The improvement of the property of continuing generating the short pulse of high power, without this hybrid mode locking operating state having stable pulse separation compared with passive mode locking operating state, and being maintained for a long time for 10 minutes or more being observed, and a frequency changing at all to change of the outside air temperature of abundance was found. Moreover, the electro-optics component drive frequency band which can obtain a hybrid mode locking oscillation was 5Hz. A pulse tip output is 1.5W and the full width at half maximum of the pulse evaluated with the autocorrelation plan became clear [that it is 700 femtoseconds]. Furthermore,

when the drive frequency of an electrooptical modulator 34 was driven according to the harmonic frequency of a mode locking frequency, it became clear that a hybrid mode locking oscillation is realizable on the repeat frequency of 8MHz which is in agreement with the 2nd harmonic frequency.

[0024] By arranging an electrooptical modulator by this example at the character type Phi Eve laser cavity of 8, stabilization of pulse separation is possible and it is clear for a high repeat pulse oscillation to be attained by the higher-harmonic drive of an electrooptical modulator.

[0025] The configuration of the pulse laser concerning the 3rd example is shown in drawing 4 . This example integrates components other than the nonlinear optics medium of the 2nd example, and an electrooptical modulator on the same substrate.

[0026] In this example, it is integrating by wiring by the quartz system flat-surface optical waveguide formed on the silicon substrate 36, and forming an optical circuit, and 3dB coupler 23A, 0.98 micrometers / 1.55microm WDM coupler 26for excitation optical multiplexing A, and coupler 29A for outgoing radiation light ejection are also formed of quartz system flat-surface optical waveguide. Germanium is added by the core of this quartz system flat-surface optical waveguide as an additive for refractive-index control.

[0027] Optical waveguide 25A for magnification as a magnification medium consists of quartz system optical waveguide which added Er ion. Er addition waveguide length of Er addition concentration is 10cm 2% of the weight. In order to add Er to homogeneity by high concentration, Lynn and aluminum are coadded to the optical waveguide 25A core for magnification. On the other hand, it arranges and accumulation mold optical-isolator 28A pastes the slot which formed the optical isolator of the structure (200 micrometers in thickness) which put the YIG magneto optics crystal permuted with Bi ion with the minute polarizer which consists of a dielectric and metaled mutual multilayers with the dicing saw so that quartz system optical waveguide might be crossed so that only the TE mode of optical waveguide may be penetrated.

[0028] As a nonlinear optics medium, with a die length of 30m polarization-maintaining-optical-fiber 27A was used. Moreover, polarization maintaining optical fiber was used for I/O using the lithium-niobate optical waveguide type phase modulator which diffused and produced titanium ion as electrooptical-modulator 34A. The optical axis was adjusted and the polarization maintaining optical fiber used for I/O of polarization-maintaining-optical-fiber 27A as a nonlinear optics medium and electrooptical-modulator 34A carried out adhesion immobilization so that plane of polarization might become the direction of a waveguide substrate, and parallel. The perimeter of the character type ring resonator of 8 of this this example is 30.5m, and a mode locking frequency is 6.6MHz.

[0029] Light which carried out polarization composition of the output light of two strained layer superlattice semiconductor laser in the pulse laser of this example (the wavelength of 0.98 micrometers) By making the output of 200mW into excitation light, through WDM coupler 26A, input into optical waveguide 25A for magnification, and passive mode locking actuation is carried out. The place which drove electrooptical-modulator 34A near the pulse repeat fundamental frequency in this condition, The hybrid mode locking oscillation could be obtained, stabilization of pulse separation is possible and it became clear for a high repeat pulse oscillation to be attained by the higher-harmonic drive of an electro-optics phase modulator. this time -- a pulse output -- 0.1W and pulse width -- 2.3psec(s) it was . Since the resonator configuration of this example can do cavity length short, it is suitable for the high repeat oscillation. Moreover, as a result of constituting the whole resonator from the flat-surface optical waveguide and the

optical fiber which have polarization holdout, destabilization of the oscillation mode resulting from fluctuation of plane of polarization can be inhibited, and practicality is high.
[0030]
[Effect of the Invention] In the pulse laser which used the nonlinear optics loop-formation mirror, the pulse laser of this invention incorporates a light modulation element into a resonator, and since it is made to perform hybrid mode locking actuation which performs passive mode locking and compulsive mode locking to coincidence, it does so the effectiveness that stabilization of the pulse separation to disturbance, such as temperature and vibration, is attained. Moreover, in the pulse laser of this invention, it becomes possible by driving a light modulation element with the harmonic frequency of a mode locking frequency to raise a repeat frequency. Furthermore, since the pulse laser of this invention generates a light pulse on the frequency which was completely in agreement with the electrical signal which drives an optical modulator, it can synchronize electrically between the light source and a detection system, and also has the advantage that various application is attained in optical information processing or optical sensing.

TECHNICAL FIELD

[Industrial Application] This invention relates to the pulse laser in which actuation stable at high power and a high repeat with high utility value is possible in the field of ultra high-speed optical communication, optical information processing, and optical sensing.

PRIOR ART

[Description of the Prior Art] 1.55-micrometer band passivity mode locking optical fiber laser using the nonlinear optics property of an optical fiber is developed using the optical fiber which added Er ion as a magnification medium, and various application as the ultrashort pulse light source is expected. Moreover, semiconductor laser excitation is possible for this pulse laser, and it has high practicality from the ability to miniaturize.
[0003] The basic configuration of an example of this kind of pulse laser is shown in drawing 5 . As shown in this drawing, the laser cavity of the shape of a character of 8 is constituted by connecting the 1st loop formation 1 and 2nd loop formation 2 through 3dB coupler 3. The optical fiber 5 as the polarization compensator 4 and a nonlinear optics medium, the coupler 6 for excitation optical multiplexing, and the erbium (Er) ion addition fiber 7 are infixed in the 1st loop formation 1, the optical isolator 8 and the coupler 9 for outgoing radiation light ejection are infixed in the 2nd loop formation 2, respectively, and the 1st loop formation 1 functions as a nonlinear loop-formation mirror.
[0004] In this pulse laser, by introducing the pump light from semiconductor laser etc. from the coupler 6 for excitation optical multiplexing, and exciting the absorption band of Er ion of Er ion optical fiber 7, switching of a nonlinear loop-formation mirror takes place, and optical fiber laser carries out a passive mode locking oscillation. Here, it circulates through light as follows in the character-like resonator of 8. The light pulse which passed along the optical isolator 8 circulates

through the 1st loop formation 1 which is the nonlinear loop-formation mirror which consists of 3dB coupler 3, the polarization compensator 4, an optical fiber 5, a coupler 6 for excitation optical multiplexing, and an Er ion addition optical fiber 7 right-handed rotation and in the counterclockwise direction, and returns to the 2nd loop formation 2 which it was again multiplexed with 3dB coupler 3, and the optical isolator 8 entered. Then, only the pulse spread to an one direction will carry out incidence to a nonlinear loop-formation mirror again with an optical isolator 8, and the pulse spread to an opposite direction is prevented. When optical reinforcement is small, the phase contrast of the light which circulates through the inside of a nonlinear loop-formation mirror is zero, and a pulse is prevented from the property of a nonlinear loop-formation mirror by the incidence port with the return optical isolator 8. If optical reinforcement becomes high, while spreading the inside of an optical fiber, phase contrast arises between the propagation directions of a pulse by self-phase modulation, and light switches to an outgoing radiation port other than an incidence port. In case the pulse which grew from spontaneous emmision luminous-intensity fluctuation spreads the inside of a resonator in the above-mentioned path, light modulation is received with the period which was in agreement with the pulse circumference time amount of a resonator with switching of a nonlinear loop-formation mirror, and a passive mode locking oscillation is caused. The self-phase modulation in an optical fiber is very high-speed, and a very short high power mode locking pulse train is acquired as a result of high-speed switching of a nonlinear loop-formation mirror, and the soliton effectiveness.
[0005] In addition, it is reported that Richardson and others realized the period of 10GHz, and passive mode locking actuation beyond presumed peak intensity 50W repeatedly by pulse width 320fs by the system shown in drawing 5 (D. J.Richardson et al;"320fs SOLITON GENERATION WITH PASSIVELY MODE-LOCKED ERBIUM FIBER LASER.";ELectron Lett.1991.27.p.730-732).

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TECHNICAL PROBLEM

[Problem(s) to be Solved by the Invention] However, passive mode-locking actuation of said pulse laser is very sensitive to fluctuation of the plane of polarization by few change and impacts of optical-resonator length in which induction is carried out by the temperature change, for example, the temperature-change width of face which stabilizes and operates is 1 or less time, and operates to stability only less than 1 minute, but the trouble about the stability of actuation -- two or more pulses occur or fluctuation of pulse separation becomes large -- which should be solved practically is in the mode-locking primitive period which becomes settled in cavity length.
[0007] This invention aims at being high power and offering the pulse laser in which stable actuation is possible by the high repeat in view of such a situation.

MEANS

[Means for Solving the Problem] The pulse laser concerning this invention which attains said purpose is a pulse laser equipped with the nonlinear loop-formation mirror and the optical isolator into the optical resonator constituted by optical waveguide, and is characterized by providing a light modulation element in the above-mentioned resonator while it uses as a magnification medium optical waveguide which added rare earth ion.

OPERATION

[Function] The so-called hybrid mode locking oscillation which performs both passive mode locking and compulsive mode locking to coincidence is realized by arranging an optical modulator in a resonator and driving an optical modulator on the frequency near the mode locking frequency which becomes settled by cavity length, or its harmonic frequency. Since a passive mode locking oscillation pulse can be compulsorily synchronized with the electrical signal which controls an optical modulator by this, a very stable short light pulse oscillation is attained to disturbance, such as temperature and vibration. Moreover, since this pulse laser generates a light pulse on the frequency which was completely in agreement with the electrical signal which drives an optical modulator, between the light source and a detection system, it can synchronize electrically and various application of it is attained in optical information processing or optical sensing.

EXAMPLE

[Example] Hereafter, this invention is explained based on an example.
[0011] The basic configuration of the pulse laser of this invention is shown in drawing 1 . As shown in this drawing, by connecting the 1st loop formation 11 and 2nd loop formation 12 which consist of optical waveguides, such as an optical fiber and flat-surface optical waveguide, through 3dB coupler 13, the laser cavity of the shape of a character of 8 is constituted, and the optical amplification medium 14 and the nonlinear optics medium 15 are arranged at the 1st loop formation 11. It is arranged in the 1st loop formation 11 at the location where the optical amplification medium 14 and the nonlinear optics medium 15 are unsymmetrical, and the 1st loop formation 11 functions as a nonlinear optics loop-formation mirror. Moreover, the optical isolator 16, the optical coupler 17 for output light ejection, and optical modulator 18 for 1.5-micrometer bands are arranged at the 2nd loop formation 12. Here, an optical isolator 16, the optical coupler 17 for output light ejection, and an optical modulator 18 can be mutually arranged in the 2nd loop formation 12 in the location of arbitration. In addition, in the 2nd loop formation 12, the necessary polarization compensator which does not carry out location illustration can be arranged if needed.
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waveguide which added rare earth ion, such as Er ion, are used. Since gain required of short waveguide length can be acquired in this by using the flat-surface optical waveguide which can be added by high concentration for rare earth ion, it becomes possible to raise the repeat frequency of a mode locked laser. In addition, as rare earth ion, others and neodium (Nd) ion, PURASEOJIUMU (Pr) ion, etc. can be mentioned. [ion / Er]
[0013] As a nonlinear optics medium 15, a silica glass fiber and flat-surface optical waveguide are usable. A very short pulse can be generated using the optical soliton effectiveness by using the optical fiber and flat-surface optical waveguide which adjusted distribution to the negative value with 1.5-micrometer band especially. Moreover, the waveguide which can spread light, with plane of polarization maintained, such as flat-surface optical waveguide and polarization maintaining optical fiber, is useful, when there is no problem of fluctuation of the plane of polarization by disturbance and mode locking actuation is carried out at stability.
[0014] As for 3dB coupler 13 or the optical turnip 17 for output light ejection, the directional coupler of an optical fiber mold with the high controllability of a branching ratio with small optical loss or a flat-surface waveguide mold is used. Since cavity length can be shortened like the case of an optical amplification medium by using a flat-surface optical waveguide type directional coupler, it is advantageous to high repeat actuation of a mode locked laser.
[0015] As an optical isolator 16 for 1.5-micrometer bands, an optical isolator with the optical fiber for I/O and the integrated thing with flat-surface optical waveguide can be used. It has the high polarization dependency which the flat-surface waveguide integration mold optical isolator suitable for the high repeat of a light pulse has the structure which put the YIG magneto optics crystal permuted with Bi ion with the minute polarizer which consists of mutual multilayers of a dielectric and a metal, and could make it 200 micrometers or less in thickness, and a thin shape, and was suitable for single polarization actuation. Therefore, high isolation can be obtained according to the magneto-optical effect by impressing a magnetic field in parallel with the propagation direction of light. In order to integrate this optical isolator with flat-surface optical waveguide, a slot is formed by etching or machining so that the optical waveguide used as an optical path may be crossed, it arranges so that it may become the suitable polarization direction about a thin optical isolator in this slot, and it embeds with the optical adhesives which optical waveguide and a refractive index adjusted, and the magnet for magnetic field impression is arranged on this after immobilization. In order to attain low loss-ization at this time, while becoming thin about the thickness of an optical isolator, the diameter of the mode field of the part which inserts an optical isolator is enlarged, and it is still more nearly required to double the refractive index of optical adhesives with an optical isolator etc. By making full use of such a low loss-ized technique, 1dB or less of insertion losses and the high quality integration optical isolator beyond isolation 20dB are realizable.
[0016] The various optical modulators using the electro-optical effect and an acousto optic effect as an optical modulator 18 are used. Both intensity modulation and the phase modulation of a modulation technique are usable. The electrooptical modulator suitable for a high repeat has the type in which the electrode was formed on the optical waveguide which used and formed the ion diffusion method in the lithium-niobate crystal front face.
[0017] In order to operate the pulse laser of this this invention, an optical modulator 18 is driven with the mode locking repeat frequency decided from cavity length, or its harmonic frequency. The so-called thing [carrying out hybrid mode locking actuation] which perform both passive mode locking and compulsive mode locking to coincidence by this is possible. If a difference with the drive signal frequency of an optical modulator 18, a mode locking frequency, or its

harmonic frequency is less than several Hz, a hybrid mode locking condition is maintainable. For this reason, it is the frequency which was not based on minute change of the cavity length by the temperature change, but was completely in agreement with optical modulator drive signal frequency, and a driving signal and the pulse corresponding to 1 to 1 can be generated. By driving an optical modulator 18 by the higher harmonic of a mode locking frequency, it becomes possible to raise pulse repetition frequency to the frequency which was in agreement with drive signal frequency.

[0018] Moreover, in the pulse laser of this invention, by constituting all or some of resonators using polarization maintaining optical fiber with polarization holdout, or flat-surface optical waveguide, fluctuation of the plane of polarization which a mechanical shock etc. produces owing to can be inhibited or controlled, and stabilization of a mode locking pulse is possible.

[0019] The configuration of the pulse laser concerning the 1st example is shown in drawing 2 . The laser cavity of the shape of a character of 8 is constituted by connecting the 1st loop formation 21 and 2nd loop formation 22 through the optical fiber coupler 23 with the branching ratio of 3dB with 1.55-micrometer band, as shown in this drawing. Er ion addition optical fiber which is the optical fiber 25, the 0.98 / 1.55WDM coupler 26 for an excitation light input, and magnification medium of 1.55-micrometer negative distribution which are the polarization compensator 24 and a nonlinear medium at the 1st loop formation 21 (Er concentration of 500 ppm) The optical isolator 28 and the optical coupler 29 for outgoing radiation light ejection are arranged for 27 die length of 15m at the 2nd loop formation 22, respectively. Moreover, the acoustooptics component 30 as an optical modulator is arranged at the 2nd loop formation 22, and the driver 31 for acoustooptics components is connected to the acoustooptics component 30. Furthermore, DC power supply 32 and an oscillator 33 are connected to the acoustooptics component driver 31. The perimeter of the character type ring resonator of 8 of this pulse laser is 50m, and a mode locking frequency is 4MHz. In addition, as the excitation light source for introducing PORUPU light (excitation light) through the WDM coupler 26, strained layer superlattice semiconductor laser (oscillation wavelength of 0.98 micrometers, 100mW of optical outputs) was used.

[0020] In the pulse laser of this example, through the WDM coupler 26, incidence of the excitation light is carried out to Er ion addition optical fiber 27, it carried out passive mode locking actuation, and the oscillation condition that two or more pulses existed in the pulse repetition period which adjusts excitation light power and the polarization compensator 24, and is determined by cavity length was acquired. When the acoustooptics component 30 was driven on the frequency near pulse repeat fundamental frequency by this condition at 10dB of extinction ratios, the process which shifts to the hybrid mode locking condition that the oscillation period of an outgoing radiation light pulse is completely in agreement with the period of a sound component driving signal, and only one pulse exists in a drive signal cycle was observed with the photodetector and the oscilloscope. The improvement of the property of continuing generating the short pulse of high power, without this hybrid mode locking operating state having stable pulse separation compared with passive mode locking operating state, and being maintained for a long time for 10 minutes or more being observed, and a frequency changing at all to change of the outside air temperature of abundance was found. Moreover, the acoustooptics component drive frequency band which can obtain a hybrid mode locking oscillation was 4Hz. A pulse tip output is 1W and the full width at half maximum of the pulse evaluated with the autocorrelation plan became clear [that it is 800 femtoseconds]. Furthermore, when the drive frequency of the acoustooptics component 30 was driven according to the 2nd harmonic frequency of a mode

locking frequency, it became clear that a hybrid mode locking oscillation is realizable on the repeat frequency of 8MHz which is in agreement with the modulation frequency of the acoustooptics component 30.

[0021] By arranging an acoustooptic modulator by this example at the character type fiber laser resonator of 8, stabilization of pulse separation is possible and it is clear for a high repeat pulse oscillation to be attained by the higher-harmonic drive of an acoustooptic modulator.

[0022] The configuration of the pulse laser concerning the 2nd example is shown in drawing 3 . Since this example is the same as that of the 1st example except using an electro-optics component instead of an acoustooptics component as a light modulation element, the explanation which gives the same sign to the member which shows the same operation, and overlaps is omitted. Moreover, cavity length and a mode locking frequency are the same as the 1st example. The light modulation element of this example is the lithium-niobate optical waveguide type electro-optics modulator 34 on the strength which diffused and produced titanium ion, and the oscillator 35 is connected to the electro-optics modulator 34 on the strength.

[0023] In the pulse laser of this example, incidence of the excitation light from strained layer superlattice semiconductor laser was carried out to Er ion addition optical fiber 27 through the WDM coupler 26 like the 1st example, and the Er ion addition optical fiber 27 concerned was excited, excitation light power and the polarization compensator 23 were adjusted, and it changed into the passive mode locking oscillation condition. And when the electro-optics component 34 was made to drive by 10dB of extinction ratios near the mode locking fundamental frequency, the process which shifts to the hybrid mode locking condition that the oscillation period of an outgoing radiation light pulse is completely in agreement with the period of an electro-optics component driving signal, and only one pulse exists in a drive signal cycle was observed with the photodetector and the oscilloscope. The improvement of the property of continuing generating the short pulse of high power, without this hybrid mode locking operating state having stable pulse separation compared with passive mode locking operating state, and being maintained for a long time for 10 minutes or more being observed, and a frequency changing at all to change of the outside air temperature of abundance was found. Moreover, the electro-optics component drive frequency band which can obtain a hybrid mode locking oscillation was 5Hz. A pulse tip output is 1.5W and the full width at half maximum of the pulse evaluated with the autocorrelation plan became clear [that it is 700 femtoseconds]. Furthermore, when the drive frequency of an electrooptical modulator 34 was driven according to the harmonic frequency of a mode locking frequency, it became clear that a hybrid mode locking oscillation is realizable on the repeat frequency of 8MHz which is in agreement with the 2nd harmonic frequency.

[0024] By arranging an electrooptical modulator by this example at the character type Phi Eve laser cavity of 8, stabilization of pulse separation is possible and it is clear for a high repeat pulse oscillation to be attained by the higher-harmonic drive of an electrooptical modulator.

[0025] The configuration of the pulse laser concerning the 3rd example is shown in drawing 4 . This example integrates components other than the nonlinear optics medium of the 2nd example, and an electrooptical modulator on the same substrate.

[0026] In this example, it is integrating by wiring by the quartz system flat-surface optical waveguide formed on the silicon substrate 36, and forming an optical circuit, and 3dB coupler 23A, 0.98 micrometers / 1.55microm WDM coupler 26for excitation optical multiplexing A, and coupler 29A for outgoing radiation light ejection are also formed of quartz system flat-surface optical waveguide. Germanium is added by the core of this quartz system flat-surface optical

waveguide as an additive for refractive-index control.
[0027] Optical waveguide 25A for magnification as a magnification medium consists of quartz system optical waveguide which added Er ion. Er addition waveguide length of Er addition concentration is 10cm 2% of the weight. In order to add Er to homogeneity by high concentration, Lynn and aluminum are coadded to the optical waveguide 25A core for magnification. On the other hand, it arranges and accumulation mold optical-isolator 28A pastes the slot which formed the optical isolator of the structure (200 micrometers in thickness) which put the YIG magneto optics crystal permuted with Bi ion with the minute polarizer which consists of a dielectric and metaled mutual multilayers with the dicing saw so that quartz system optical waveguide might be crossed so that only the TE mode of optical waveguide may be penetrated.
[0028] As a nonlinear optics medium, with a die length of 30m polarization-maintaining-optical-fiber 27A was used. Moreover, polarization maintaining optical fiber was used for I/O using the lithium-niobate optical waveguide type phase modulator which diffused and produced titanium ion as electrooptical-modulator 34A. The optical axis was adjusted and the polarization maintaining optical fiber used for I/O of polarization-maintaining-optical-fiber 27A as a nonlinear optics medium and electrooptical-modulator 34A carried out adhesion immobilization so that plane of polarization might become the direction of a waveguide substrate, and parallel. The perimeter of the character type ring resonator of 8 of this this example is 30.5m, and a mode locking frequency is 6.6MHz.
[0029] Light which carried out polarization composition of the output light of two strained layer superlattice semiconductor laser in the pulse laser of this example (the wavelength of 0.98 micrometers) By making the output of 200mW into excitation light, through WDM coupler 26A, input into optical waveguide 25A for magnification, and passive mode locking actuation is carried out. The place which drove electrooptical-modulator 34A near the pulse repeat fundamental frequency in this condition, The hybrid mode locking oscillation could be obtained, stabilization of pulse separation is possible and it became clear for a high repeat pulse oscillation to be attained by the higher-harmonic drive of an electro-optics phase modulator. this time -- a pulse output -- 0.1W and pulse width -- 2.3psec(s) it was . Since the resonator configuration of this example can do cavity length short, it is suitable for the high repeat oscillation. Moreover, as a result of constituting the whole resonator from the flat-surface optical waveguide and the optical fiber which have polarization holdout, destabilization of the oscillation mode resulting from fluctuation of plane of polarization can be inhibited, and practicality is high.

DESCRIPTION OF DRAWINGS

[Brief Description of the Drawings]
[Drawing 1] It is the conceptual diagram showing the basic configuration of the pulse laser of this invention.
[Drawing 2] It is the block diagram of the pulse laser concerning the 1st example.
[Drawing 3] It is the block diagram of the pulse laser concerning the 2nd example.
[Drawing 4] It is the block diagram of the pulse laser concerning the 3rd example.
[Drawing 5] It is the block diagram of the pulse laser concerning the conventional technique.
[Description of Notations]

11 21 The 1st loop formation
12 22 The 2nd loop formation
13 23 3dB coupler
14 Optical Amplification Medium
15 Nonlinear Optics Medium
16 Optical Isolator
17 Optical Coupler for Output Light Ejection
18 Optical Modulator
24 Polarization Compensator
25 Er Ion Addition Optical Fiber
25A Optical waveguide for optical amplification
26 26A 0.98 / 1.55WDM coupler for an excitation light input
27 Optical Fiber
27A Polarization maintaining optical fiber
28 28A Optical isolator
29 29A Optical coupler for outgoing radiation light ejection
30 Acoustooptics Component
34 34A Electrooptical modulator